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UNITED STATES AIR FORCE RESEARCH LABORATORY

THE FUNDAMENTAL SKILLS TRAINING PROJECT

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August 2003

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14. ABSTRACT
From 1990 to 2000, the Air Force Research Laboratory (AFRL), with strong support from the University of Texas at San Antonio, engaged in research to bring state-of-the-art intelligent tutoring technology to bear on our nation's growing literacy skills problem in areas such as mathematics, writing, and science. The primary goals of the Fundamental Skills Training (FST) Project were to design and develop, implement, evaluate, and transfer intelligent tutoring systems (ITSs) to participating public schools and, when appropriate, to industry under federal technology transfer guidelines. ITSs are automated training systems that deliver individualized instruction. These systems are possible through the application of artificial intelligence principles to computer-based training and education. Recent ITS research in training and education demonstrated a level of maturity that made this technology transfer feasible and worthwhile. In the FST project, tutors were built to supplement the work of the teacher in the classroom. The intelligent tutoring systems, therefore, were not intended to replace teachers, but rather to help teachers cope with the demands of teaching an increasingly challenging student population. The goal of this report is to summarize AFRL's ten-year FST Project.

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TABLE OF CONTENTS

PREFACE

This paper is a summary of the Air Force Research Laboratory's Fundamental Skills Training (FST) Project. It is designed only to be an overview of the project. Many other papers containing details of the technical effort have been written and published.

Over the ten years of the project, many individuals have contributed to the project. The following people contributed significantly to the project. Many not listed below also contributed, but not to the extent as those listed here:

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THE FUNDAMENTAL SKILLS TRAINING PROJECT

1 GOAL OF THE FUNDAMENTAL SKILLS TRAINING PROJECT

From 1990 into 2000, the Air Force Research Laboratory (AFRL), with strong support from the other AFRL research sites---Phillips (NM), Rome (NY), and Wright (OH)--as well as the University of Texas at San Antonio (UTSA), had been engaged in a long-term research project. This project brought state-of-the-art intelligent tutoring technology to bear on our nation's growing literacy skills problem in areas such as mathematics, writing, and science.

The primary goals of the Fundamental Skills Training (FST) Project were to **design and develop, implement, evaluate, and transfer** intelligent tutoring systems (ITSs) to participating public schools and, when appropriate, to industry under federal technology transfer guidelines. ITSs are automated training systems that deliver individualized instruction. These systems are possible through application of artificial intelligence principles to computer-based training (CBT) and education. Recent ITS research in training and education demonstrated a level of maturity that made this technology transfer feasible and worthwhile. In the FST project, tutors were built to supplement the work of the teacher in the classroom. The intelligent tutoring systems, therefore, were not intended to replace teachers, but rather to help teachers cope with the demands of teaching an increasingly challenging student population.

The goal of this report is to summarize AFRL's ten-year FST Project.

2 INTELLIGENT TUTORING SYSTEMS

The following tutoring systems were developed and evaluated under the FST Project. Of these, the Information Technology Tutor is not an intelligent tutoring system, but rather follows a traditional CBT system design.

2.1 MTutor

The first iteration of the word problem-solving tutor, known as MTutor, was implemented at one high school in San Antonio, TX, in September 1991. The tutor taught students to:

- Define the goal (specify the goal of the problem, known values, and unknown values),
- Represent the problem (Build a graph, spreadsheet, or diagram),
- Solve the problem (Make an equation and answer the question), and
- Reflect (Take notes and list the steps used to solve the problem).

In the pilot evaluation, eight teachers used the tutor with over 400 students for approximately 20 class periods (50 minutes each) over the academic year. The control students were in another demographically similar high school.

2.2 The Word Problem Solving Tutor

Based on the evaluation results on the first year, the FST team decided to design and develop a second iteration based on the lessons learned from the first version of the word problem-solving (WPS) tutor. This version was first used in the high schools in the Fall of 1992 and was revised during the subsequent years. A more detailed description is presented in Appendix A.

The new version consists of 23 independent modules of instruction that correspond to critical curriculum elements in beginning algebra. As an ITS, it differs from traditional computer-based instructional systems in that it uses artificial intelligence to carefully and automatically tailor instruction for each individual student. One of the strengths of WPS is that it boosts confidence and mathematical proficiency by using dynamic, self-paced, adaptive instruction and determines when remedial instruction is required, providing it only when necessary. Students progress from easy problems explained in the computer-based tutorial to difficult problems that require a greater skill level.

WPS was designed to enhance, not replace, traditional classroom instruction. During the course of traditional instruction, classes use WPS to work individually and receive automated feedback and guidance from the tutor. This frees the teacher to work individually with students who are having a particularly difficult time learning the basic concepts.

2.3 Reading and Writing in a Supportive Environment

The Reading and Writing in a Supportive Environment (R-WISE) software was the first writing skills tutor. R-WISE was a classroom-based, adaptive, supportive learning environment for strengthening critical thinking skills associated with several writing tasks. The writing tasks implemented in R-WISE were based on the work of cognitive psychologists who studied the writing process and identified a number of common strategies employed by emergent and expert writers. These strategies relate to pre-writing, text generation, and editing activities. R-WISE included adaptive computer-based instruction, generated on a just-in-time basis, to meet the specific needs of the student while learning these strategies. R-WISE also included a composition help system.

R-WISE was tested and evaluated by ninth-grade English classes in 20 high schools in five different U.S. States over the period 1992-1995. The purpose of the evaluations was to determine whether the supportive environment of R-WISE could help students improve critical thinking skills related to writing. Results over the last five years show students who used the writing tutor improved their overall writing skills from 8% to 26%.

2.4 Maestro: The Writing Process Tutor

Maestro: The Writing Process Tutor is a student-oriented computer-based program designed to improve the overall writing quality and analytical reasoning skills of writers. Maestro's design is based on the cognitive theory behind the early FST writing tutor, R-WISE. It is a classroom-based, adaptive, supportive learning environment for strengthening the critical thinking skills associated with varying writing tasks. Its comprehensive instructional approach provides up front instruction in the writing process and individualized adaptive advice at critical points in each workspace. Incorporating motivational features that address individual characteristics such as learning styles and interests, Maestro presents 15 dynamic interfaces, over 100 tailored instruction modules (TIMs), and 575 tutoring advice statements. The student's writing process is monitored and coached by an intelligent advice system. A more detailed description is presented in Appendix B.

This tutor supports expository, persuasive, research and practical writing styles with over 100 challenging, multimedia writing assignments. Maestro offers the traditional classroom teacher full control over these assignments, as well as the capability of entering other assignments as deemed necessary by the nature of the curriculum or the individual writing student.

2.5 Writing Process Tutor - Java Version

The goal of the Writing Process Tutor - Java (WTPJ) Version was to design, implement, and evaluate an internet-based version of Maestro: The Writing Process Tutor. The interfaces and curriculum of Maestro were adapted for use in WPTJ. While the two writing process tutors are similar in instructional goals, there are some differences between the two. The differences result from the use of Java for the Internet version and Asymetrix's Toolbook for the original local area network (LAN)-based system.

2.6 Instruction in Scientific Inquiry Skills Tutor

Instruction in Scientific Inquiry Skills (ISIS) Tutor uses ecological concepts to teach scientific inquiry skills. It uses a gaming environment as a motivational feature to provide tutoring on the difficult task of teaching scientific methods that include making observations, generating hypotheses, designing and conducting experiments, drawing conclusions, and accepting/rejecting hypotheses. This ITS teaches ecology concepts in areas including biomes, abiotic factors of plant growth, biotic factors in ecosystems, human activities, and ecology principles. See Appendix C for more information on ISIS.

Using a cognitive apprenticeship approach to teaching, ISIS implements *modeling* through 19 Skill Instructional Modules (SIMs), with over 40 Domain Instructional Modules (DIMs) on ecology topics. Through *scaffolding*, students learn and perform skills incrementally by addressing one of over 300 research questions. In a simulated environment, students conduct real-time research developing their scientific skills. A gaming character provides advice and feedback. The advice then *fades* as the student becomes more proficient. After the assignment, students *reflect* by answering questions designed to apply their newly acquired knowledge.

2.7 Information Technology Tutor

The goal of the Information Technology Tutor (IT Tutor) is to teach basic computer-related skills and knowledge. After having completed the IT Tutor, entry-level students should be prepared to learn more from subsequent IT instruction. The IT Tutor covers basic keyboard layout and functions, mouse use, computer hardware components, Microsoft Windows interface and software, the Internet, and electronic mail. The IT Tutor is geared toward young adults who have little to no knowledge or experience with personal desktop computers. Students who are familiar with today's software may find some sections helpful while other sections may be more of a review of what they already know. More advanced students may find the IT Tutor "too simple." Instructors should become familiar with the IT Tutor curriculum and assign students to use it on an "as needed" basis. Staff may use the IT Tutor for their own staff development too. The IT Tutor presents computer concepts in straightforward, simple, and direct instruction. The instruction should not be viewed as training on specific applications, but rather on general concepts, which apply to different kinds of software. More importantly, the IT Tutor is designed to complement, but not replace human-delivered instruction. That is, the IT Tutor is only an introduction to computer concepts that should be followed by more in-depth teaching by instructors in the classroom.

The initial version of the IT Tutor was delivered to the Department of Labor in July 2000. Subsequent to the FST Project, an enhanced version was developed and delivered in March 2001. The IT Tutor was distributed nation-wide in a series of training sessions conducted by the National Office of the Job Corps later that year.

3 PARTNERS

In the prime years of the FST Project, the Air Force Research Laboratory (formerly Armstrong Laboratory) was strongly supported by the sibling Air Force laboratories: Wright Laboratory (Dayton, OH), Rome Laboratory (Rome, NY), and Phillips Laboratory (Albuquerque, NM). These laboratories not only contributed funding for the design, development, and evaluation of the FST tutors, but they also sponsored test and evaluation sites in their local community. In 1992, the FST Project expanded from one test and evaluation site to nine. Seven were under sponsorship of the Air Force laboratories, one under the sponsorship of UTSA, and one under the sponsorship of Lehigh University. The latter two sponsors were part of a Cooperative Research and Development Agreement (CRDA) signed in 1991 (See the Technology Transfer section).

In 1997, the Department of Defense (DoD) and the Department of Labor Employment and Training Administration (DOLETA) began a cooperative effort to transition the FST products from the military to DOLETA workforce development settings. This support was provided to install the FST tutors in DOLETA-sponsored settings, to design and develop the Java version of the writing process tutor, and to design and develop the IT Tutor. Finally, the Northeast Independent School District of San Antonio, TX, provided the Air Force with a premier test facility, MacArthur High School, beginning in September 1991.

4 USERS

Over the ten years of the FST project, the FST team attempted to implement and evaluate the intelligent tutoring systems in a variety of educational settings with varying degrees of success. As mentioned, Department of Labor sites were added to the FST project in 1997. In addition, the FST team's participation in a DOLETA project lead to a group of users for the IT Tutor. The full list of sites involved to some degree in the FST project is listed in Appendix D.

For the most part, the high schools participating in the project under support of AFRL or UTSA attended training, used the tutors for the suggested number of hours per year, and completed the pretest and posttest. As support for the schools participating in the FST Project waned, so did the schools' completion of the evaluation requirements. The Department of Labor sites, however, did not exhibit the same level of compliance with the FST requirements. In some cases, instructors were trained to use the tutors, were excited about doing so, but then were not able to actually begin using the tutor. There were several unforeseen factors influencing whether students used the tutors. One example was a lack of functional hardware. In one setting, there simply were not enough functional computers for the instructor to use the tutors effectively. (These factors are briefly described in the Implementation Model and Timelines section.)

4.1 High Schools

As mentioned above, the FST project grew in the number of schools participating in the project in a series of steps. The project began in 1991 with one high school and expanded to nine schools in Fall 1992 in New York, Pennsylvania, Ohio, New Mexico, and Texas. Under funding from Phillips Laboratory, an additional 17 schools in New Mexico were added beginning in 1995 bringing the total to 40 high schools.

4.2 Job Corps Centers, Youth Fair Chance, Career Advancement Centers

The FST team began working with Department of Labor sites in June 1997 at a training session in Baltimore, MD. The sites included Job Corps Centers (JCCs), Career Advancement Centers (CACs), and Youth Fair Chance (YFC) sites. Several additional JCCs were added to the FST project and Labor's IT Pilot Project.

5 TECHNICAL AND PROFESSIONAL SUPPORT

During the first year of the project, the FST team realized that the project would entail more than simply designing and developing software. Carefully planned and executed implementation of the software was necessary so that empirically sound evaluations could be conducted. Not only was teacher training on the software critical, but also user manuals and other teacher-related documents had to be produced. In addition, communication with the sites became an important activity. The following are examples of the technical and professional support activities accomplished by the FST team throughout the project.

5.1 Teacher Training Sessions

Teacher training was one major component of the professional support provided by the FST team. The FST team conducted 72 teacher-training sessions between August 1991 and January 2000. Teacher training sessions were most often held in August or September prior to the Fall semester or at least in the first few months of the school year. In some cases, such as for the Job Corps instructors, training occurred in "off" months (e.g., January 2000). Most training sessions were held at high schools in San Antonio, TX, and Albuquerque, NM, but occasionally training sessions were held in other locations: Dayton, OH; Allentown, PA; Rome, NY; Los Lunas, NM; Baltimore, MD; Bangor, ME; Montgomery, AL; and Long Beach, CA.

Teacher training sessions adopted a consistent pattern over the years. Each session covered a short overview of the FST project, background on the design of the tutoring system, a demonstration or "walk-through" of the student portion of the tutor, several hours of hands-on time, training on the teacher utilities, and guidance on how to integrate the use of the tutor into the teacher's existing curriculum. Training on the word problem-solving tutor lasted one day, science 1 ½ to 2 days, and writing 1 ½ to 2 days, depending on the size of the audience.

5.2 Training Materials

Training materials were developed and maintained throughout the life of the FST Project. At the beginning of a teacher training session, each teacher was given a copy of the training materials, which included an agenda, a point of contact sheet, descriptions of the software, teacher responsibilities, evaluation data from previous school years, a user manual, teacher guides, teaching tips, lab manuals, and forms.

5.3 User Manuals

As mentioned, user manuals for each tutor were developed and updated with each release of the software. These were distributed as part of the teacher training and whenever a new version of the tutoring systems was distributed to the schools. The user manuals covered the standard topics: the nature of the tutoring system, how to use it, how to install it, and how to use the teacher toolkits (i.e., teacher management utilities).

5.4 Teacher Guides

In addition to the usual user manuals, the FST team developed a teacher guide or laboratory manual for each tutoring system. These differed across the three tutors because the needs of the teachers in each discipline had different teaching needs. For the word problem-solving tutor, a laboratory manual containing a listing of all of the word problems used within the tutor was given to the teachers. This listed the word problem text and a correct solution path for that word problem. For RWISE and Maestro, a teacher's guide was produced. This guide contained activities the English teachers could use in their traditional classroom to support the instruction included in the tutor. For each step of the writing process, the guide contained worksheets that could be copied and distributed to the students. For ISIS, a lab manual included a listing of the

research assignments, a printout of the glossary, a listing of the tutor's independent variables, their units of measurement, and equipment used to measure the variables. Each of these guides or manuals was distributed at the teacher training sessions or when major revisions occurred.

5.5 Communication with the Schools

As mentioned, the FST project involved more than installing software in the schools and collecting data. Communication with each school was crucial especially during the first year in working with a school. Several "site coordinator" meetings were held during the first few years of the project to transfer information to the sites, give status reports to the sites, and to listen to issues and problems at each site. Phillips Laboratory in Albuquerque sponsored similar meetings for the 19 test and evaluation sites in New Mexico.

As technology evolved over the decade, the nature of the communication changed. The FST team and evaluation site personnel communicated through the standard technologies of telephone, mail, and facsimile. A few video teleconferences (VTCs) were held with teachers and government points of contacts by using the VTC capabilities at the local sponsoring Air Force laboratory. Almost humorously, some schools in the early years of the project had to unplug their single phone into the school to receive a fax from the FST team. E-mail was not heavily used until the final years of the FST Project, because schools and teachers were late in adopting the use of e-mail.

6 DEVELOPMENT CYCLES AND TEAMS

The design and development processes and timelines were very consistent over the life cycle of each tutoring system. The timeline was not explicitly planned, but resulted due to the constraints of the academic calendar of the test and evaluation sites. That is, the FST team needed to release an updated version of the software and conduct training near the beginning of each school year. The development of the software, curriculum, and supporting materials had to be completed by early to mid-August each year.

6.1 Sources of design information

Even though the designs of the various tutors were conducted by different design teams, the sources of information were consistent across the tutors. First, researchers perused theoretical literature in each domain. For instance, writing process theories were reviewed and considered for implementation. Theories and models from cognitive psychology, educational psychology, and computer science were also reviewed. Second, researchers reviewed published and non-published literature for empirical research studies for information, which might facilitate the design of the tutor. Finally, "best practices" were collected from master teachers participating in the design of the tutors and, in some cases, teachers who had been using previous versions of the tutoring systems. The information gleaned from these sources was then synthesized into a coherent design for each tutor.

6.2 Timelines

The timelines for the development, implementation, and evaluation of each tutor was constrained by the academic calendar of the participating schools. In general, the initial design and software development for each tutor took one year. During the summer months prior to a tutor's pilot test, master teachers developed the curriculum, teacher guides, and contributed to the writing of a user manual.

The timelines for the second and subsequent years of each tutor was fairly consistent across the tutors. The following list of events and months is typical:

- Teacher training was conducted in August.
- A new tutor version was tested and distributed in August or early September.
- Students completed the evaluation pretests in September.
- Site visits and teacher surveys or interviews were conducted from late Fall through mid-Spring.
- Master teachers developed additional or enhanced existing curriculum materials throughout the academic year.
- Students completed the posttests in April or May.
- The evaluation data were collected, analyzed, and summarized in June and July.
- Tutor design changes, curriculum development, and software changes were made during the summer months prior to the new release in August.

6.3 Teams

Each of the intelligent tutoring systems described above were designed, developed, and evaluated by an interdisciplinary team. Major design decisions for a tutor were made either by the entire design team or a subset with at least one member from each of the disciplines listed below.

- Master teachers wrote curriculum materials, instructor guides, and user manuals. They also provided tutor instructional design guidance, information on "best teaching practices," and professional support, such as teacher training. English, math, and science teachers not only contributed to the tutors in their own discipline, but also to other tutors. For instance, the English teachers reviewed the curriculum materials of all three tutors. In addition, one of the science teachers wrote word problems for WPS. Math teachers reviewed instruction on graphing which was included in the science tutor.

- Computer programmers were responsible for the design and development of the software. They participated in all design meetings even if the focus of the meeting was on the curriculum or instruction to be embedded within the tutoring system. Additionally, they provided technical support for the sites (e.g., during installation) and wrote installation documents, support documents (e.g., frequently asked questions), and design documents.

- Research psychologists reviewed relevant theoretical and empirical research literature leading toward the design of the tutors. They drafted summaries of instructionally effective design principles, wrote user manuals, provided professional and technical support for the schools, develop and administered the pretests and posttests, analyzed the evaluation data, wrote technical papers, gave presentations to professional and management organizations, and maintained the website.

- For each tutor, a team lead managed and directed the interdisciplinary team. Across the life of the project, the team leads came from different professional backgrounds. For instance, one was a cognitive psychologist, one was a technical writing instructor at an engineering school, one was an educational technology specialist, and one was an educational psychologist.

- Site coordinators, while not part of the "core" tutor design and development teams, played an important role in the implementation and evaluation of the tutors. Each of the evaluation sites were asked to pick an individual in a school, preferably a teacher, who would be the prime point of contact for the FST team. These individuals were responsible for scheduling and maintaining the computer labs, coordinating the evaluations, distributing and collecting surveys of the teachers, communicating with the FST team, and keeping their school administrators informed about the project status.

7 EVALUATION

One of the primary goals of the FST project was to assess the instructional effectiveness of the implementation of the tutoring systems in public education settings. From 1991 through 1998, the FST team conducted 17 academic year-long evaluation studies of the instructional effectiveness of the FST tutors. A brief summary of the methodology is followed by short descriptions of selected studies. Appendix E, a summary of the 17 evaluation studies, was written for educational administrators.

7.1 Methodology

A variety of evaluation methodologies were used over the course of the project. Some studies included control groups in demographically similar high schools, whereas others included control groups within the same high school. Several studies were conducted to replicate the initial evaluations, but did not include a traditional control group.

The FST pretests and posttests required more of the students than traditional multiple-choice tests assessing students' knowledge. The subtle distinction is the difference between "knowing what" and "knowing how." Each test was designed to explore students' ability to perform the skills being taught in the tutors.

- WPS was evaluated with multiple-choice tests asking questions about the word problem-solving process, such as "What is the goal of the word problem?" These questions went beyond the traditional word problem-solving questions in which the student must simply choose the correct answer to the word problem. The questions in the WPS tests were

designed to assess detailed aspects of the problem solving process, not just the final answer.

- RWISE and Maestro evaluations required students to write either a five-paragraph persuasive or expository essay. These writing samples were scored by independent raters who were given rubrics (i.e., scoring guidelines) for each of five scales. These included a holistic score and several analytical scores: abstraction, organization, development, and purpose.

- ISIS pre- and post-tests were multiple-choice tests covering the scientific inquiry skills and ecology content.

In the early days of the project, the tests were given in a paper-and-pencil fashion. FST team members served as proctors in each classroom during the pretests and posttests to ensure the tests were given correctly and the students completed the tests. In the later years of the project, during the replication studies, the test was given in a computer-based testing format.

7.2 Outcomes

The details of each evaluation study methodology and results are beyond the scope of this report. A summary of the results is listed in Appendix E. For details of specific studies, the reader should read the relevant papers listed in Appendix F. Nonetheless, one example study for each of three tutoring systems is presented here.

WPS

The initial evaluation of WPS was conducted with 632 students in seven high schools in three states. The seven schools were randomly assigned as control sites, placebo-treatment sites, and treatment sites. At the control sites, students exposed to traditional instruction enhanced their word problem-solving performance by 19% over the course of a school year. At the placebo-treatment sites, students who solved these problems using the same problem-solving software but with the cognitive pedagogy removed enhanced their problem-solving performance by 19%. At the treatment sites, students who were exposed to WPS enhanced their word problem-solving performance by 29% over the same period. In comparison to traditional instruction of word problem solving, the placebo treatment had no effect on learning, and WPS reliably enhanced learning. In subsequent year-long evaluations, the results supported these findings.

Maestro

Maestro was designed as a follow-on tutor to R-WISE, based on results of the R-WISE studies, teacher input, cognitive research into the writing process, and the cognitive apprenticeship instructional strategy. The functionality and efficacy of the initial version of Maestro was tested in a large-scale pilot study. The study groups include classes of 54 teachers at 23 schools. Similar to results with the other tutors in the FST suite, student gains were directly influenced by the amount of time spent on the Writing Process Tutor. Specifically, students spending at least 11 hours using Maestro improved by 11% while the control group improved by only 3%.

ISIS
A large-scale test of the effectiveness and implementation of ISIS was conducted in 14 schools in five states. There were over 30 teachers using ISIS in 83 sections of ninth-grade biology. There were 46 sections in the same high schools serving as non-treatment control groups. The FST team also investigated the feasibility of using ISIS in seventh-grade honors biology and explored several research questions concerning the use of concept mapping in a knowledge-rich domain. In terms of overall gains, the treatment group improved by 8%, while the control group improved by only 4%. Specifically, the skill level obtained by the students directly influenced the amount of gain. Students who used the tutor more gained more than the control group or students who used the tutor for only a few hours.

8 IMPLEMENTATION MODEL AND TIMELINES

One goal of the FST Project was to implement the tutoring systems in educational settings. The phrase "Go work with public education" was one of the initiating directions for the project. As mentioned in the discussion of the users, the FST Project focused its efforts on 40 high schools supported by AFRL or UTSA funding. Implementing the tutoring systems became relatively routine by the third or fourth year of the project. In the later years, the FST project expanded to Job Corps Centers, Youth Fair Chance Centers, and Career Advancement Centers under funding from the Department of Labor Employment and Training Administration (DOLETA). As a result, the FST Project team began to experience users who did not fit the traditional public education model. Things didn't always go as planned. As an example, the FST staff trained instructors from several Job Corps Centers. In some cases, the instructors returned and used the tutors, but in other cases, the instructors did not. Because of the experiences with the high schools and DOLETA sites, the FST team developed two models concerning educational technology projects and the activities needed to support new and existing users.

8.1 Implementation Model

The implementation model posits factors that affect student-learning outcomes during the use of technology in education and training settings (see Figure 1). The full implementation model includes:

- Teacher variables such as workload, training, motivation;
- Technology variables including technical support, hardware, software;
- Student variables such as motivation, access, history;
- Administrators and external requirements, such as system mandated curriculum;
- Project staff; and
- Learning outcomes (i.e., what students learn). (This is affected by the quantity of time students interact with the software and the quality of that interaction.).

The FST team found that a deficiency in one or more of these factors could negatively impact the students' learning outcomes.

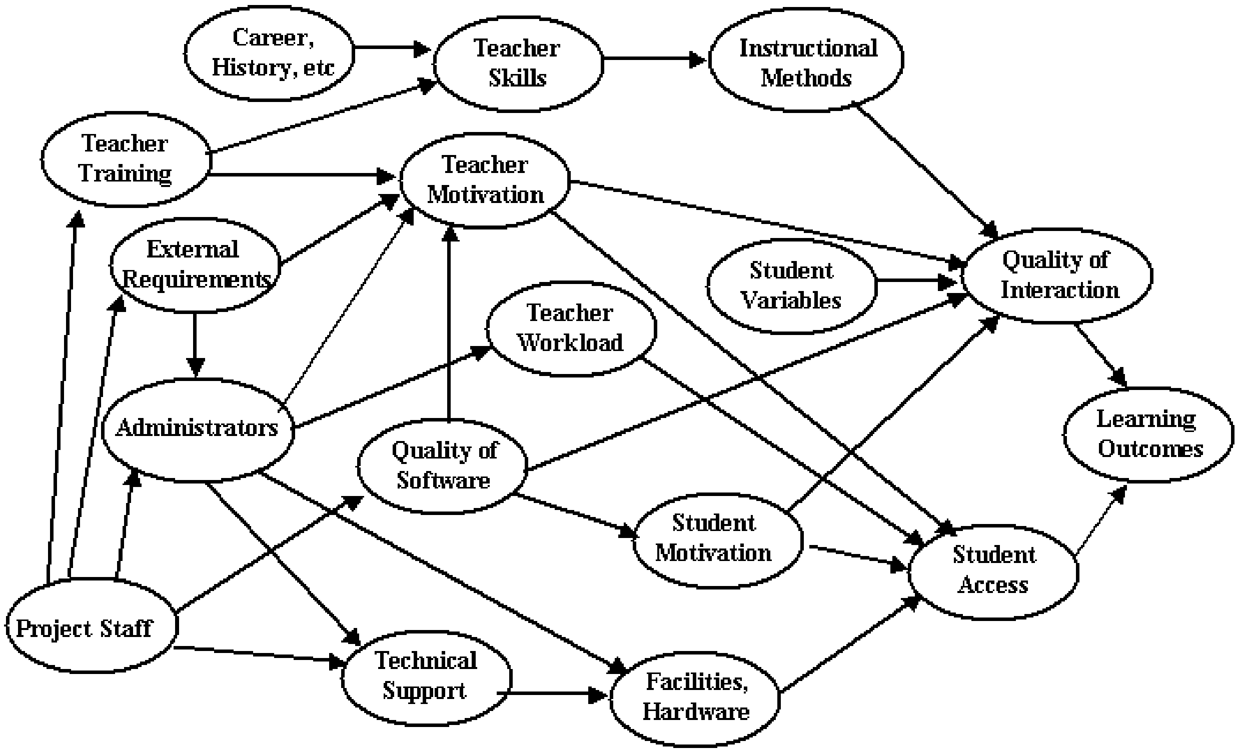

Figure 1. A model of implementation factors.

Project Staff

- The project staff should be an interdisciplinary team of administrators, expert teachers, educational/instructional psychologists, computer programmers, and researchers. Decision-making throughout the life of the project should take into account each of these perspectives.
- Project staff influence the quality of the training teachers receive.
- The project staffs' implicit or explicit theories/models of education influence the design of the software. The quality of the software in turn impacts the quality of the students' interaction with the domain information and the students' motivation to use the software.

Administrative Factors

- Administrators affect the quantity of time students interact with domain concepts via the software by their decisions in setting up and maintaining the computer facilities and by hiring (or not hiring) technical support. If the facilities (including hardware and software) are not maintained, student access time drops.
- Administrators not only play a role in providing opportunities for learning by providing adequate facilities, but they also influence students' access to the content by influencing teachers' workload. If teachers are burdened with non-technological duties, they will not have the time to learn and implement the technology appropriately.
- Administrators also affect teachers' motivation by giving incentives, stipends, workload reduction, or by placing requirements on them to use the hardware and software.

Teacher Factors

- Teachers' motivation to use learning technology is directly impacted by their administrators, training on the hardware and software, and external requirements. External requirements may include state-mandated testing, grant, and/or contract requirements.
- Teachers' skills are influenced by their educational background and history with the domain and technology. Their skills are also influenced by the quality of training they receive on the technology, and the time they have to use the software after training. These, in turn, affect how they interact with the students and the software.

Technology Factors

- The quality of the software affects whether students are motivated to use the software and the quality of the interaction between students and the domain information.

Student Factors

- Students' motivation to learn the domain information is affected by the quality of the software and by their own personal goals. If they are not interested in learning, their time on task drops.

Implications of the Model

The model can be used in planning and managing a project that implements educational technology. The model may also be used in a wide variety of educational settings, such as public or private schools, and adult education. Guidelines for project staff, administrators, and teachers can be derived from the model.

8.2 Timelines

Twenty-one events described the life span of an instructional technology project. The events are broadly categorized under four activities: Project Start-Up, Site Start-up, Long-Term Use, and Project End.

Project Start-Up

- Project Start-up refers to the first few months of a project during which decision-making and planning determine the project's goals, team members, curriculum and software design, target population, target teachers, and funding strategy.
- Project Start-up incorporates such steps as project plan approval, software/curriculum development, and initial contact with the potential user.

Site Start-up

- Site Start-up refers to the events in which the project staff begins to work with the target users.
- Site Start-up deals with administrator training, teacher training, and the initial use by teachers.

Long-Term Use

- Long-term Use refers to the events that occur during the "stable" portion of a project. This usually begins in the second or third year of a project.

- Long-term Use includes site visits by the project staff, site coordinators' meetings, and ways to assist the teachers in using the technology after the initial projected has ended.

Project End

- Project End concerns the preparation of sites to use the technology as part of their normal/routine activity without project staff support.

Notes About The Timeline

- The timeline is descriptive, not prescriptive. Not all events will occur within all projects.
- Some steps are discrete (i.e., short duration in time) while others are continuous events (i.e., happen over a long period of time).
- Some events occur in a natural order (Idea inception "initiates" the project) while other events occur at various times along the timeline with multiple occurrences being possible.
- The importance of events within a project varies. For instance, teacher training is much more important than publicity events.

9 PRESENTATIONS AND PAPERS

The FST team literally gave hundreds of presentations and/or demonstrations to federal, state, and local government employees; faculty and students in high schools and universities; professional organizations, and many other distinguished visitors.

Project overviews and/or demonstrations of the tutors were given to the following dignitaries:

- Then President William Clinton
- Then Texas Governor George W. Bush
- U.S. Senator Kay Bailey Hutchinson Staff
- U.S. Representative Ciro Rodriguez and Staff
- State Senator Joseph Luna
- San Antonio Mayor Nelson Wolff
- General Yates (AFSC/CC)
- General Richard Paul (AFRL/CC)
- Dr Joseph Osterman (OSD)
- Andrew Hartman (National Institute for Literacy)
- Mary Silva (Director of the National Office of Job Corps)
- Russell Kile (Vice President's National Partnership for Reinventing Government)
- Donald Johnson (OUSD)
- The National Board of the American Society for Training and Development

By no means is this a complete list. To its credit and distraction, the FST Project was a highly visible project within the Air Force. FST personnel were requested to give numerous demonstrations and presentations, as were many of its sibling projects. In one 5-month period (January - May 1995), the FST team gave 110 presentations and/or demonstrations of the tutors!

As part of its research mission, the FST team wrote research papers, which were presented at professional conferences. These papers and presentations are listed in Appendix F.

10 AWARDS

The FST Project Team won several awards during its ten-year run. These include:

Hammer Award from Vice President Al Gore (Feb 1999). The FST Team received Vice President Gore's prestigious Hammer Award, which recognized organizations and agencies that streamlined government operations and improved how they delivered services. Specifically the award recognized the work on WPTJ, an intelligent tutoring system designed to deliver writing process instruction over the Internet.

The Department of Labor's Certificate of Excellence (1996). Robert Reich, then Secretary of the Department of Labor, presented a Certificate of Excellence to the FST team for its work with the Department of Labor service providers.

Armstrong Laboratory, Human Resources Directorate Customer Support Excellence Award for 1996. The Customer Support Excellence Award was given to the FST team for the support given to teachers and administrators in over 50 high schools and workforce development settings.

Federal Laboratory Consortium Award for Excellence in Technology Transfer for 1995. The Federal Laboratory Consortium for Technology Transfer presented an award to the FST team for its work in transferring the word problem-solving tutor to a commercial partner. This was one of the first transfers of educational technology outside of the Air Force.

The Alamo Federal Executive Board 1994 Quality Award. The Alamo Federal Executive Board awarded the FST team the 1994 Quality Award for maintaining high standards in research and working with customers.

Champion of Education Award (1992). The San Antonio Independent School District presented the FST team their "Champion of Education Award" for the team's work with Sam Houston High School in San Antonio, TX

The Lone Star Salute to Community Service (1992). The FST team was designated as a 1992 Star of Texas by the Texas Community Education Association for its innovative efforts at Mac Arthur High School in the North East Independent School District.

11 TECHNOLOGY TRANSFER

The fourth goal of the FST project was to transfer the technology out of the federal laboratory setting to commercial partners. This also was accomplished to varying degrees of success. The following is a quick summary of the history of the first FST CRDA.

- Cooperative Research and Development Agreement
  - Signed 29 April 91
  - Signatories included Armstrong Laboratory, The University of Texas at San Antonio, SAGE Educational Systems, and Lehigh University

- Modification 1 to the CRDA
  - Date signed is unknown
  - Goal: To terminate rights of SAGE Educational Systems and Lehigh University

- Modification 2 to the CRDA and Appendix E
  - Signed 13 Sep 94
  - Signatories include Armstrong Laboratory, The University of Texas at San Antonio, and PWS Publishing, Inc.
  - Goal: To license the Word Problem Solving Tutor (WPS) to PWS

- Modification 3 to the CRDA
  - Signed Feb 97
  - Signatories include Armstrong Laboratory, The University of Texas at San Antonio, and Brooks/Cole Publishing
  - Goal: To change the licensee from WPS to Brooks/Cole Publishing.

- Modification 4 to the CRDA
  - Signed by UTSA and Armstrong Laboratory, but not by Brooks/Cole.

- Letter of Termination
  - Signed by Brooks/Cole on 7 Jul 99

APPENDIX A: THE WORD PROBLEM SOLVING TUTOR

Goal of Tutor
The goal of the Word Problem Solving Tutor is to teach students have to analyze word problems and generate correct solutions in a variety of mathematical areas.

Curriculum

Skills
WPS is an intelligent tutoring system that teaches students to analyze and solve word problems in five steps:

1. Identify the goal of the problem
2. Identify the values necessary to solve the problem
3. Make an equation
4. Solve the equation
5. Answer the question using the appropriate solution value and units of measure.

The Tutor does not teach mathematical calculation but is designed to be used as a supplement to traditional classroom instruction that includes mathematical calculation.

Math Modules
The WPS Tutor consists of 23 independent modules covering pre-algebra, algebra, and geometry. Each of the 23 modules has a review module.

Algebraic Equations	Integer Math
Equations In Geometry	Number Sequences
Pythagorean Theorem	Decimals
Area Of Circles	Percentages
Formulas	Proportions
Ratio	Area Of Triangles
Area Of Quadrilaterals	Circumference Of Circles
Fractions	Perimeters
Area Of Shapes	Volumes Of Solids
Surface Areas Of Solids (5 Modules)	

Intended Audience

WPS is appropriate for middle and high school students along with adults pursuing a GED.

Instructional Features

Tutorials. Each module begins with a computer-based tutorial that uses animation, graphics, and text to review the appropriate subject material. In addition to this review, the tutorial contains a worked example of a sample problem, questions to test students' knowledge of the material, and a summary page.

Levels of Difficulty. After successful completion of the tutorial, students are presented with a set of word problems organized by level of difficulty. The problems in the first level of difficulty are isomorphic to the example problem in the tutorial. This equation is also the simplest version of the equation for that module. Each subsequent level is only slightly more difficult than the previous level, and the source of additional difficulty is explicitly taught in the Tutor.

Help. The WPS software provides several levels of help for the student. For example, students may access help in the form of hints for the word problem they are working to solve. Other help includes interface help, a quick tour of WPS, and a review the units of measure module.

Tools. As students seek to complete the five problem-solving steps, the interface design of WPS allows the student to readily access a myriad of assistive tools and tables. For each problem, students have access to a

- weights and measurement table,
- formulas table,
- glossary,
- notebook,
- lesson summary, and
- graphic that goes with the word problem.

Interfaces

WPS has one primary interface in which the students perform the word problem solving skills. Students click on the goal statement, identify relevant variables and their values, generate and equation, and then answer the question. The row of buttons along the top is used by the students to access various useful tools.

Theoretical/Development Background

The WPS Tutor is pedagogically based on five cognitive theoretical foundations, including learning by practice (Anderson & Fincham, 1994; Blessing & Anderson, 1996; Lovett & Anderson, 1994), elaboration (Reigeluth, 1987, 1992), categorization (Rosch, 1978), mastery (Kulik, Kulik, & Bangert-Drowns, 1985; Slavin, 1990), and induction (Reed & Bolstad, 1991; Reed, Willis, & Guarino, 1994; Ward & Sweller, 1990).

Practice. Theory: Learning and skill acquisition occur when students are taught the required declarative knowledge and then are required to actively process the information or practice the skill.

WPS: Students learn declarative knowledge in the subject (e.g., area of shapes) and pass a test on that knowledge before they are allowed to practice solving problems in that domain.

Elaboration. Theory: Students begin by practicing the epitome of a skill, and then practice progressively and systematically more complex versions of the skill.

WPS: Students are first presented with the simplest possible version of the relevant formula. As students progress in the Tutor, steps are added to the formula, making it more difficult and complex.

Categorization. Theory: An appropriate way to organize the subject information is specified and then explicitly taught to students. Information is organized around prototype concepts, which become the center for conceptual categories.

WPS: Students are presented with a prototype formula in each module. As students practice their skills, they build expertise and (ideally) recognize that new problems require solution strategies that are minor variations on known strategies.

Mastery. Theory: When a complex skill is to be taught based on important prerequisite skills, the curriculum must be ordered appropriately. In addition, an appropriate level of mastery for each skill is insured before advancement is allowed.

WPS: Students are allowed to progress to a new level or module only when they have mastered the current level or module. The instructor can set mastery requirements.

Induction. Theory: Students are shown how to solve examples of the kinds of problems they will encounter. Student can solve new isomorphic problems by mapping steps from the worked example onto the new problem.

WPS: Each module of the WPS Tutor presents worked examples of word problems. Then students are given isomorphic problems to solve.

Evaluation

WPS has been tested since 1992 in some of the largest field studies of educational technology ever conducted. Students at secondary and middle schools in Ohio, Texas, New Mexico, New York, and Pennsylvania participated in these studies. In one study, students using the mathematical tutor improved their word problem solving skills by 29%.

Teacher Toolkit Features

The WPS software allows the instructors to create rosters, generate reports, choose the instructional mode, and set the class curriculum.

Rosters. Teachers may enter rosters, display rosters, and add, delete, or update student records. In addition, users may sort students by ID number, name, or by class.

Reports. Teachers may generate and print student reports for specific classes or for all students and may be created for specific dates. Instructors have the option to create student reports or student notebook reports. The student report includes the amount of time spent on the problem, the date the problem was completed, the type of problem, the problem ID number, the level of the problem, the number of steps the student took to complete the problem, the number of errors

committed, and the number of times the student asked for help. The student notebook report includes the notes, values, equations, and answers the student has entered.

Curriculum. Instructors may set the curriculum (see Math Modules above) for individual students as well as for entire classes. Setting the curriculum allows the teacher to determine the order that the students will see the modules.

Instructional Mode. Instructors have the option to set the instructional mode that the student will work under. WPS has a "guided mode" and a "not guided mode." When the teacher has chosen to have the students work under the guided mode, the tutor will give the student advice each time he/she makes an error. In addition, the instructional mode requires the proper completion of each step before the student is allowed to proceed. If the instructor chooses to have students work problems in the not guided mode, they will be allowed to complete steps in any order. The software will only give advice at the students' request.

Teachers can also set the parameters WPS uses to make decisions about the student. For example, based on their knowledge of students' skills and abilities, teachers can set the number of problems students are required to solve per module, the number of levels of difficulty they are required to achieve per module, and the number of times they are allowed to ask for help per problem. By giving the teacher the option of changing the number of times a student may ask help the software allows the teacher to can ensure that the student progression is due to learning and not abuse of the help system. If a student requests help too many times, he/she will not get credit for the assignment and will be asked to repeat it without asking for so much help. Instructors may also choose to allow the student's performance, as measured by the software, to guide the student through the software. If the teacher select the "By Performance" option, the software will determine the number of problems he/she must complete in mastering a skill, the number of helps allowed for the student, and a range of acceptable errors and steps that are deemed acceptable for the student's current level of performance.

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APPENDIX B: MAESTRO: THE WRITING PROCESS TUTOR

Goal of Tutor

Maestro: The Writing Process Tutor facilitates the development of basic writing process skills. The tutor guides students through prewriting, drafting, revision, and editing phases of the writing process, while helping them to structure writing activities, and develop the cognitive skills used in writing.

Curriculum

<u>Writing Process</u>

Prewriting. While working in this stage, the writer will identify goals, analyze the audience, decide the style and purpose, and develop a thesis. Students will also generate ideas using one of the four idea tools: clustering, outlining, note taking, and cubing. Students also construct a writing plan during their prewriting activities.

Composing a draft. Draft helps writers use their ideas to compose well-written sentences and form effective paragraphs.

Editing. Writers are first guided through the revising process by selecting appropriate questions to apply to the composition. Students using the tutor revise on different levels: Whole Paper, Introduction, Body, Conclusion, and Sentence.

Publish allows the writer to tailor the written presentation to the audience. It provides workspaces for proofreading, formatting, highlighting, and distributing their work.

<u>Types of Writing</u>

Maestro supports most writing purposes including expository, persuasive, research, and practical. Teachers can choose the type of writing required of the students and the specific challenging assignments presented by Maestro.

Expository Writing. Expository essays explore and present information to a reader. Students are guided throughout the development of a multi-paragraph composition. Most of these essays will entail a process or incident.

Persuasive Writing. The purpose of a persuasive essay is to influence or change a person's opinion about a specific topic. In Maestro, persuasive essays may take the form of editorials, letters, or opinion pieces.

Research Writing. Research writing requires a well-documented and carefully planned report. These research papers may be either informative or analytical.

Practical Writing. Practical writing prepares students to structure their writing to achieve joint understanding with their readers. This aspect of the tutor is designed to be relevant in today's business environment: *résumé, cover letter, business letter, memo, and e-mail.* Students are guided through the actual writing process and provided with feedback to ensure that their work meets quality standards of the business world.

Intended Audience

Maestro was initially developed for ninth-grade students, but has been extended to middle school and young adult populations, such as those attempting to complete a GED.

Instructional Features

Tailored instructional modules (TIMs). TIMs are short, simple instruction focused on the specific writing needs of each student. TIMs are adaptive to the interests and learning styles of individual students for each stage of the writing process including goal-setting, generating and organizing ideas, generating a writing plan, drafting, revising, and publishing.

Student Controlled Workspaces. Student-controlled workspaces designed to facilitate the development of skills associated with the stages of the writing process. The workspaces adapt based on the type of writing required of the student.

Challenging Assignments. Situated assignments help motivate students by using multimedia-based stories and realistic writing tasks.

Intelligent Advice. An intelligent advisor tutors student by monitoring student progress, providing diagnostic advice, presenting appropriate TIMs, and managing workspaces.

Interfaces

There are over 20 different interfaces or workspaces for the students to use while developing writing process skills. These are selected and presented by the intelligent controller within Maestro.

Teacher Toolkit Features

The design of Maestro allows it to be integrated into any writing curriculum. Teachers manage the rosters, lessons, writing assignments, reports, and testing.

Rosters. Teachers enter class rosters, display rosters, and add, delete, or update student records.

Class Lessons. Teachers construct lessons by selecting one or more writing assignments for the students to select.

Writing Assignments. Teachers can author new writing assignments tailored to their students, curriculum, and local community. Each assignment can include a writing prompt, a reading, a

picture or graphic, and a video. Teachers also determine the number of paragraphs the students must complete, the type of writing, and which workspaces are required or available for the students to use.

Reports. Teachers can view on the computer screen or print out the class rosters, students' profiles, their writing in each and every workspace, or a summary of the students' progress.

Pretesting and Posttesting. Teachers can give an automated pretest and posttest using the teacher tools.

APPENDIX C: INSTRUCTION IN SCIENTIFIC INQUIRY SKILLS (ISIS)

Goal of Tutor

Instruction in Scientific Inquiry Skills (ISIS) tutor focuses on developing students' critical thinking skills, scientific literacy, and scientific inquiry skills in the context of ecology and the life sciences.

A goal of science education is to produce students who are competent in science. By "competent in science," the project team means that each student will be literate, functional, and critical in the domain of science. To be literate denotes the abilities to obtain, comprehend, and communicate scientific material. To be functional refers to the ability to utilize the methods, principles, and technologies that pertain to science. To be critical indicates the abilities to assess the soundness of scientific approaches and outcomes and to judge the significance of science and technology in society.

Curriculum

Students are required "to do" science in ISIS. They first pick one of the more than 300 research questions from a series of concept maps. The concept maps are organized by topic areas, such as Human Activities. Once they have selected a research question, they perform the following skills in ISIS.

Skills

The over-arching goal of the science tutor, Instruction in Scientific Inquiry Skills (ISIS), is to increase the level of scientific functioning of high school students enrolled in Introductory Biology. Because this level of functioning is too broad to address in the initial design of ISIS, the tutor focuses on skills underlying scientific inquiry. Some of the activities required in applying scientific methods are automated within ISIS; other skills constitute what the students will learn by interacting with the computer. The following are the specific, measurable objectives of ISIS. Specifically, students will be able to:

- Generate a research question.
- State a testable hypothesis.
- Design a controlled experiment to test that hypothesis.
- Conduct the experiment in a simulated environment.
- State a conclusion from the experiment.
- Accept or reject hypothesis.

Domain Content

These scientific inquiry skills are taught within an environmental theme. Students learn about ecological concepts by selecting and completing research questions. These research questions are categorized into the following five major categories and their respective subcategories:

Biomes: Grasslands, Deserts, Temperate Deciduous Forests, Coniferous Forests, Tropical Rainforests, Polar Regions, Tundra, Fresh Water, Marine.

Abiotic Factors: Atmosphere, Water, Sunlight, Ph/Chemicals, Rainfall, Irradiance, Soil, Natural Disasters.

Biotic Factors: Autotrophs, Heterotrophs, Decomposers.

Ecology: Energy Flow, Natural Relationships, Material Recycling, Genetic Variation

Human Factors: Atmospheric Pollution, Land Use, Natural Resources, Habitat, Genetic Diversity, Water Pollution.

Intended Audience

The content of ISIS in which inquiry skills are taught is environmental science. As with the word problem solving and writing process tutors, the software is primarily geared toward middle, junior high, and high school populations.

Instructional Features

Research Assignments. ISIS includes over 300 research assignments including detailed information about the assignment, the correct independent and dependent variables, the correct relationship between the variables, the units of measure, equipment needed for each assignment. These are used by ISIS to monitor the student's progress as they complete a research assignment.

Simulations. ISIS includes five biome simulations (e.g., coniferous forest, deciduous forest, tundra, grasslands, desert). When conducting an experiment, students enter a simulation, set the independent variable, set the values for five experimental groups (i.e., levels of the experimental variable), and run the simulation for three growing seasons.

Skill Instructional Modules. The instructional modules are lessons on five scientific inquiry skills. After each lesson, a student progresses to the castle to complete assignments using the skills he/she has just learned. These skills instructional modules include: Generating a Hypothesis, Designing an Experiment, Conducting an Experiment, Drawing a Conclusion and Accepting or Rejecting a Hypothesis.

Generate Hypothesis: This instructional module teaches students how to develop a research question and generate a hypothesis by introducing several subskills. The subskills taught in generating a good hypothesis: observing graphs, generating observations from text, generating questions from visuals, questioning graphs, generating questions from text, generating hypothesis, testability of hypothesis, and rating scientific inquiry for importance and testability.

Designing an Experiment: This module shows students how to specify independent and dependent variables, units for the variables, a time period for an experiment, and equipment used

in an experiment. The subskills taught in designing an experiment are: identifying variables, forming test groups, measuring units and equipment, and determining time span.

Conducting an Experiment: This module shows a student how to properly organize, analyze, and display the data while the experiment is being conducted. The subskills are: executing a procedure, collecting data, and presenting data.

Drawing a Conclusion and Accepting or Rejecting a Hypothesis: This module teaches a student how to effectively interpret the data and compare the results to the hypothesis to draw a conclusion and accept or reject the hypothesis. Since this module is relatively short, the two skills are not broken into subskills.

Domain Instructional Modules. The domain instructional modules contain text and graphic information on ecology or biology concepts related to the assignments in the tutor. The student must answer questions at the end of each module to continue in the tutor.

Acid Rain	Resources	*Biomes:*
Agriculture	Seasons	Coastal Ecosystems
Atmosphere	Soil	Coniferous Forests
Biomass	Solar Radiation	Deciduous Forests
Deforestation	Succession	Deserts
Desertification	Symbiosis	Fresh Water Biome
Ecosystem	Temperature	Rainforests
Ecosystem Development		Tundra
Food Chain		Polar Regions
Freon/Chlorofluorcarbons	*Chemicals:*	
Greenhouse Effect	Carbon	
Human Population	Carbon Dioxide	
Light	Helium	
Movement of Energy and Materials	Hydrogen	
Natural Disasters	Nitrogen	
Photosynthesis	Oxygen	
Plant Structure	Ozone	
Pollutants	Water	

Pretest and Posttest. ISIS includes two pretests and posttests which the teacher can schedule using one of the teacher utilities. One pretest-posttest combination assesses student understanding and application of the scientific inquiry skills. The second combination is focused on the biology, ecology, and environmental science content.

Interfaces

The interface of ISIS is unique. Students find themselves in a medieval castle, where they must click on various objects to do an assignment. The castle includes a multitude of characters and functions:

Igor, the lab assistant, guides students and provides feedback about their performance on the each step of scientific inquiry process

Wizard gives hints about what the student is doing wrong or what is needed to complete a part of the assignment.

Magic Windows contain the ecological topics (i.e., research questions) addressed in the tutor.

Equipment Room contains supplies needed to conduct the experiment: meters, ppm meters, linear/mass devices, glassware, and timers.

Library contains the Skill and Domain Instructional Modules, a glossary, and interface help.

Glossary contains all of the words highlighted in the domain instructional modules.

Desk is where the students do their work. The desk and the area around it include a crystal ball, terrarium, notebook, conclusions book, final decisions book, skull, and a map. Students make predictions (generate a hypothesis) using the crystal ball. The terrarium is used to design and conduct their experiments. The conclusions book allows the student to draw a conclusion based on the results of the experiment while the final decisions book is where the student ultimately accepts or rejects their hypothesis.

Toolbox contains the student's notebook and equipment selected in the equipment room.

Notebook has three sections regarding their assignments: 'Current Work', 'Prior Work/Notes', and 'Assignment Information'.

Treasure Chest is where the students "spend" the points accumulated by successfully completing the assignments, SIMs, and DIMs.

Theoretical/Development Background

A cognitive apprenticeship approach to instruction is embedded in ISIS. Cognitive apprenticeship emphasizes two relevant issues. First, cognitive apprenticeship aims to teach cognitive and metacognitive skills used by experts when faced with complex tasks (Collins, Brown, & Newman, 1989; Collins, Hawkins, & Carver, 1991). Cognitive apprenticeship approaches focus on teaching students how to solve complex problems and tasks. This requires the instructor to teach declarative, procedural, and metacognitive knowledge in the context in which it is used.

The second issue addressed by cognitive apprenticeship is the actual method of teaching students. Cognitive apprenticeship relies on students learning through guided experiences (Collins, et al, 1989). Initially, an instructor models the external behaviors while describing the cognitive aspects underlying the performance of the task-related skills. Following the modeling of the skills, the student performs those skills under the direction of the instructor. The instructor guides the student through the task providing lots of structure or guidance to the student. As the student becomes more proficient in performing the task, the instructor "fades" or reduces the amount of structure. Throughout the teaching-learning episode, the student is required to reflect upon his/her performance relative to that of experts. This reflection develops self-correction and self-monitoring skills. The methods underlying a cognitive apprenticeship approach to instruction (Collins, et al., 1989) include; (a) modeling of the cognitive skills and processes underlying task performance, (b) coaching the student during his/her performance of the skills, (c) structuring of lesson content and subsequent fading of the structure, (d) requiring the student

to reflect upon his/her performance and articulate his/her knowledge, and (e) allowing students to explore how to apply newly learned information in accomplishing complex tasks.

For ISIS to accomplish the methods underlying the cognitive apprenticeship approach, the tutor must be able to perform several instructional activities. The set of activities chosen to implement the cognitive apprenticeship approach is described by Hsieh, Miller, Hicks, and Lorenz (1993). The tutor must be able to (a) present detailed domain knowledge and inquiry skills and multiple examples of each, (b) elicit performance from the student, (c) diagnose the student's performance, and (d) give appropriate feedback.

One component of instruction in the cognitive apprenticeship approach is to allow the students to explore how to apply their knowledge in accomplishing complex tasks (Collins, et al., 1989). In addition, Project 2061 states that "students need time for exploring, for making observations, for taking wrong turns, for testing ideas, for doing things over again..." (Rutherford & Ahlgren, 1990, p193). Allowing students to "play" in a computer-based simulation of the domain concepts is one way to achieve these recommendations. ISIS contains a simulation of simple ecosystems, such as a grassland and a coniferous forest, so that students can conduct experiments testing their hypotheses.

The role of a student model is to provide information to the instructional module to make instructional decisions (Self, 1990; Van Lehn, 1988). The student model is a repository of the interpretations made by the instructional module during the diagnosis of the student's behavior. The student model needs to record information for immediate, on-line, instructional and long-term, deferred, curricular decision making. The immediate decisions tend to revolve around the instructional action the tutor must take given a student's behavior. The tutor diagnoses the student's performance and then must determine whether to give any feedback and what kind. The long-term, deferred decision-making primarily involves decisions at a curricular level. Once a student has completed an assignment, the tutor needs to determine whether to advance a student to another unit of instruction or to assign a task within the same instructional unit.

The types of data recorded in a student model includes data about a student's progress through the curriculum, the student's knowledge of the biology concepts, and the student's ability to perform the skills underlying the scientific method. The curricular information includes the list of assignments completed, the current assignment, and status on the current assignment. Data on the biology concepts include whether a student has received instruction on each concept, the number of errors a student has made on the current assignment, the number of errors the student has made on previous assignments involving the concept, and a belief about the student's proficiency based on these and other data. Data on the scientific skills include whether a student has received instruction on each skill, the number of errors a student has made on the current assignment, the number of errors the student has made on previous assignments involving the skill, and a belief about the student's proficiency based on these and other data.

Evaluation

A pilot evaluation of this tutor was conducted during the 1994-1995 academic year followed by large-scale field evaluations in 1995-1996, 1996-1997, 1997-1998, and 1998-1999. Generally, students show an 11% increase in their scientific inquiry skills after having used ISIS for 15 or more hours. These studies and results are summarized in the FST Evaluation Summary and several research papers.

Teacher Toolkit Features

The ISIS Teacher Toolkit allows teachers to keep track of their students' work electronically.

Rosters. Using the Teacher Toolkit, teachers can enter student rosters, quickly find a specific user, remove a student, sort the rosters by different variables, verify login information, and edit user's information.

Generating and Printing Reports. Several types of reports may be generated. Types of reports include: Skill Proficiency Summary, Domain Reading Summary, Notebook, Class Roster, and Student ID Cards.

The Skill Proficiency Summary. This report is a detailed presentation of each student's performance on each of the scientific inquiry skills. It includes the number of assignments students have completed for each skill level, the number of errors students have made, and the number of help statements students have requested. Overall, proficiency is calculated using all completed problems.

The Domain Reading Summary. The Domain Instructional Module Summary produces information on the students' interactions with the domain instructional modules. It presents the number and amount of time each student sent in each DIM.

Notebook. Teachers can print out the students notes and research outcomes on each assignment. This is a great tool for portfolio assessments.

The *Class Roster* lists of all the students in a particular class period. The *Student ID Cards* prints labels for cards students can use to log into the software. The labels contain teacher name, period, student name, user ID, and password.

ISIS Configuration Utility and Test Utility. Instructors may enable or disable the science tests using this utility. The software may be set to give no test, give a content or skills pretest the first time a user logs on or give a matching content or skills posttest the next time a user logs on. The *Test Utility* allows teachers to view student test scores at anytime. The user may also save the results to a file or print it.

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APPENDIX D: SITES PARTICIPATING IN THE FST PROJECT

ALBUQUERQUE AND NM

Bernalillo High School
Los Lunas High School
Cuba Middle School
Manzano High School
Mesa Alta Junior High School
Silver High School
Socorro High School
West Mesa High School
La Cueva High School
Dora High School
Gadsden High School
Grants High School
Hagerman High School
Hatch High School
Hondo High School
Maxwell High School
Moriarity High School
Onate High School
Tatum High School

SAN ANTONIO, TX

Mac Arthur High School
Sam Houston High School
Harlandale Academy
Garner Middle School
Krueger Middle School
Roosevelt High School
Harlandale High School
McCollum High School
Harlandale Alt Center
South San High School
West Campus High School
Woodlake Middle School
Judson High School - Gray
St Matthew Catholic School

DAYTON, OH

Trotwood-Madison High School
Dunbar High School

ALLENTOWN, PA

Salisbury Middle School

ROME, NY

Staley Middle School
Strough Middle School
Mohawk Valley CC

DEPARTMENT OF LABOR

Penobscot Job Corp Center
Loring Job Corp Center
Westover Job Corp Center
Ouachita Job Corp Center
Dayton Job Corp Center
Hubert Humphrey Job Corp Center
Connecticut Job Corp Center
Atterbury Job Corp Center
Montgomery Job Corp Center
Bangor Career Advancement Center
Memphis Youth Fair Chance
Edinburgh Youth Fair Chance

Alaska Job Corp Center
Cascades Job Corp Center
Clearfield Job Corp Center
Hawaii Job Corp Center
Northlands Job Corp Center
Phoenix Job Corp Center
Shriver Job Corp Center
South Bronx Job Corp Center

APPENDIX E: EVALUATION SUMMARY

1. Word Problem Solving (WPS) Tutor Pilot Study

Dates: Sep 91 - May 92

Description: A pilot test was conducted to investigate the instructional effectiveness of the first version of WPS and to examine issues surrounding a long-term operational implementation of WPS in a high school setting. The treatment group consisted of 400 students in 16 sections of pre-algebra with eight teachers for approximately 20 hours of instruction. A demographically similar high school served as the non-treatment control group.

Outcome The tutored group significantly outperformed the control group on structured word problem solving exercises. In addition, their knowledge of the steps involved in solving word problems was significantly better than the control group. Several issues concerning implementation were raised, such as teacher-student-computer interaction and technical support requirements. Data from this study were applied to subsequent tutor design and implementation.

2. Word Problem Solving Tutor Large-scale Implementation Study

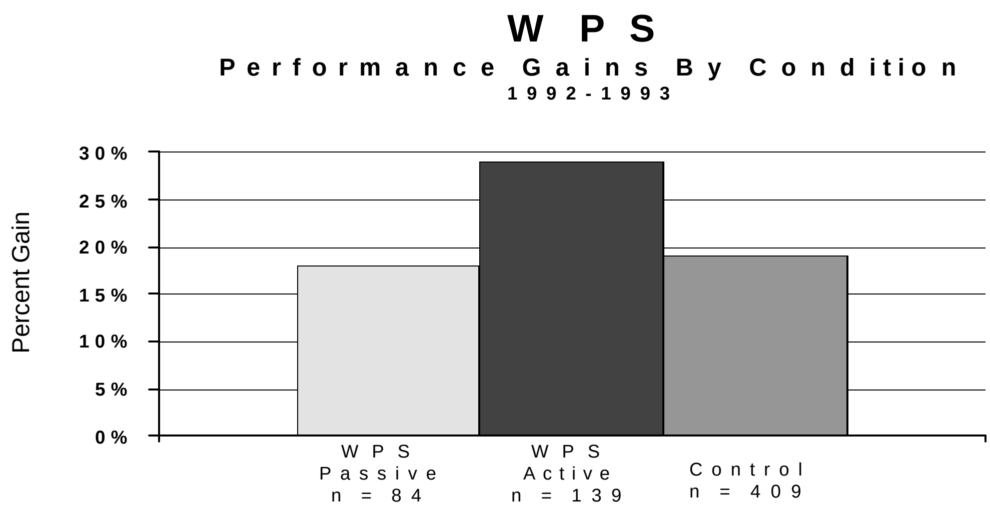
Dates: Oct 92 - May 93

Description: A large-scale evaluation of WPS was conducted at seven schools in three states across the nation. The treatment group used the WPS software plus classroom instruction, the placebo group used the same set of computerized word problems but with no theory-driven instructional approach plus classroom instruction, and the control group used traditional classroom instruction only. The study involved 632 students and 20 teachers (Wheeler & Regian, 1999).

Outcome: Students who used WPS outperformed students who used the placebo tutor and students who received traditional classroom only. The treatment group improved by 29%, while the placebo group improved by 18% and the control group improved by 19%. Further implementation issues dealing with site communication were raised and solved. In addition, differences in improvement between students' concrete reasoning skills and abstract reasoning skills were examined. In all three groups, there were larger increases in concrete reasoning performance than in abstract reasoning performance (see Table 1). The differences in change scores among the groups on both concrete and abstract reasoning scores were significant.

Table 1. Percent Changes in Concrete Reasoning Skills and Abstract Reasoning Skills.

Groups	Percent change on concrete reasoning scores	Percent change on abstract reasoning scores
WPS	31%	20%
Placebo	19%	15%
Control	22%	11%



3. Reading and Writing in a Supportive Environment (R-WISE) Pilot Study

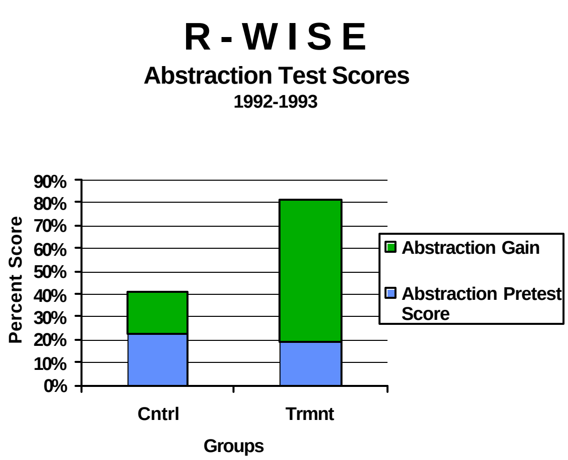
Dates: Jan 93- May 93

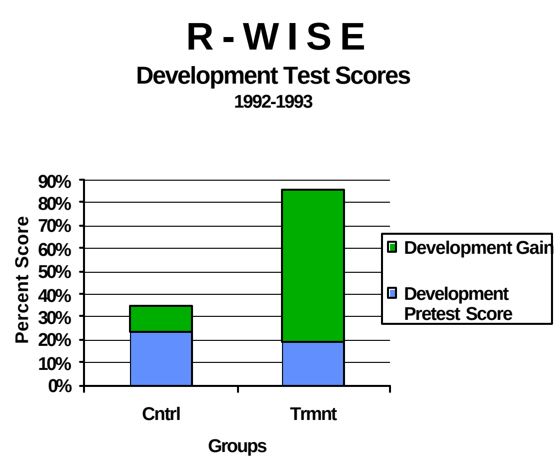
Description: The pilot test was conducted to investigate the effectiveness of the first version of R-WISE and issues surrounding a long-term operational implementation of it in a high school setting. The treatment group consisted of 430 students in 26 sections of ninth grade English, nine teachers, approximately 9 hours of instruction. Another demographically similar high school group (423 students, 22 sections, 6 teachers) in San Antonio served as the non-treatment control (Rowley, Miller, & Carlson, 1997).

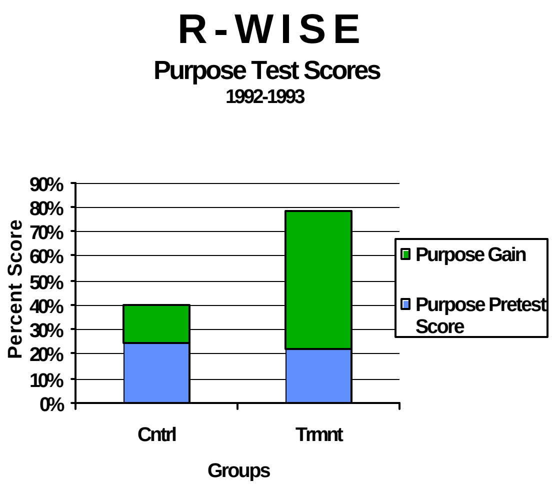
Outcome: The treatment group had higher scores on five measures of writing performance even after only nine contact hours with R-WISE. Implementation issues, such as scheduling classes into the computer laboratories, were raised and resolved.

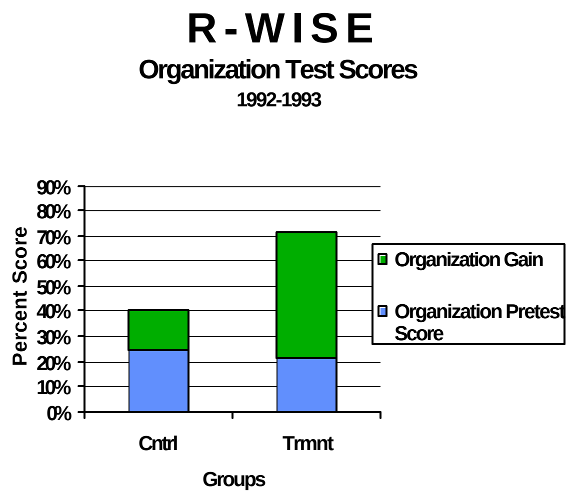
Table 2. R-WISE Holistic Pretest Scores and Posttest Results.

	Cntrl	Trmnt
Pretest Score	34%	30%
Posttest Gain	-46%	44%







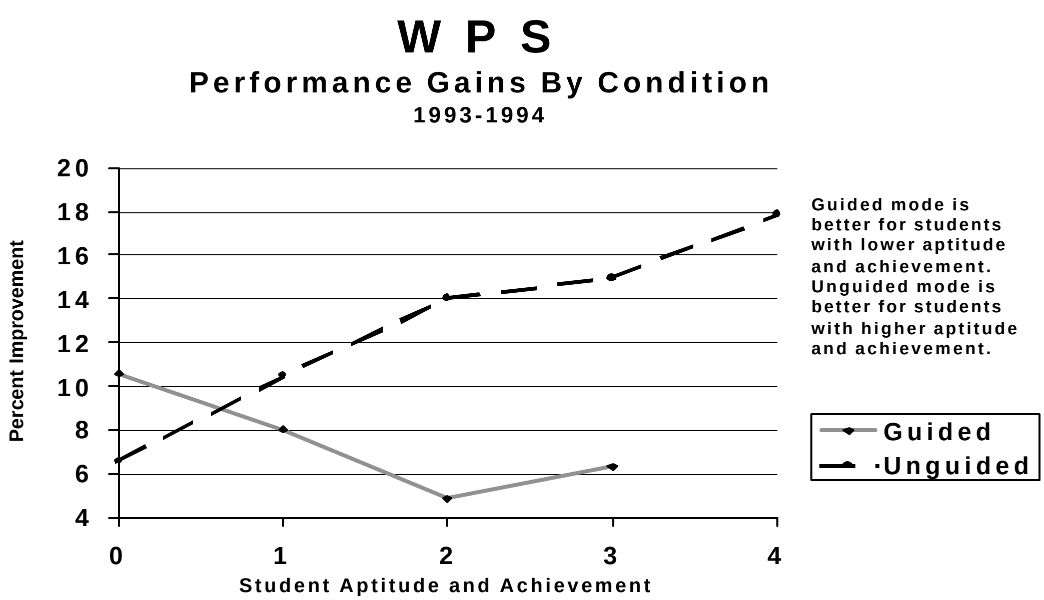


4. A Test of Two WPS Instructional Approaches

Dates: Sep 93 - May 94

Description: A study of two instructional approaches (guided and unguided) was conducted at two schools in Dayton, OH involving 194 students and 5 teachers.

Outcome: A significant aptitude-treatment interaction was found. Students with lower levels of achievement as determined by their class level performed better in the guided mode of instruction than those in the unguided mode. Students with moderate to high achievement levels performed better in the unguided mode than the guided mode.

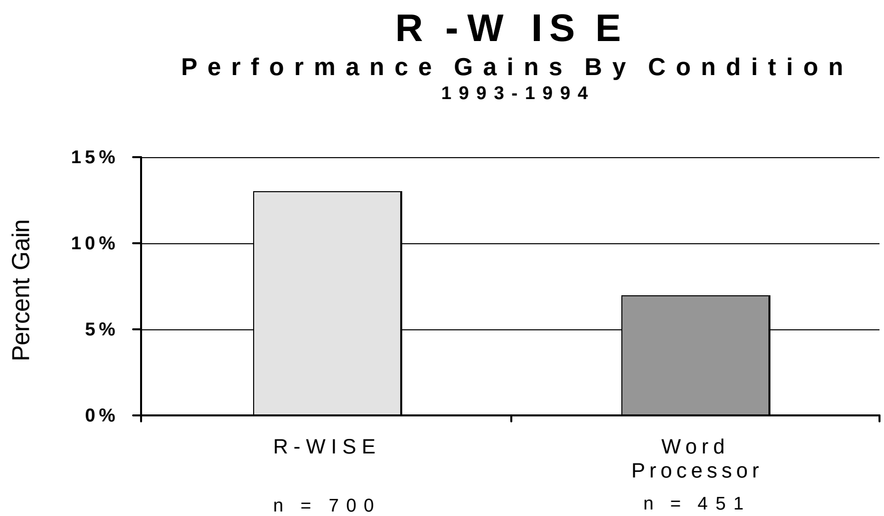


5. Reading and Writing in a Supportive Environment (R-WISE) Large-scale Implementation Study

Dates: Sep 93 - May 94

Description: A large-scale operational test of R-WISE was conducted in eight schools in five states across the nation. The treatment group (N=700 students, 17 teachers, 57 sections) used R-WISE for an average of 20 hours during the academic year. The control group consisted of 451 students and 13 teachers (37 sections) from the same high schools. The control group used a word processor for an average of 20 hours during the academic year (Rowley, Miller, & Carlson, 1997).

Outcome: The students using R-WISE significantly outperformed students learning to write using a word processor on all five measures of writing performance. The attitudes towards writing of students using R-WISE were significantly more positive than those using a word processor.

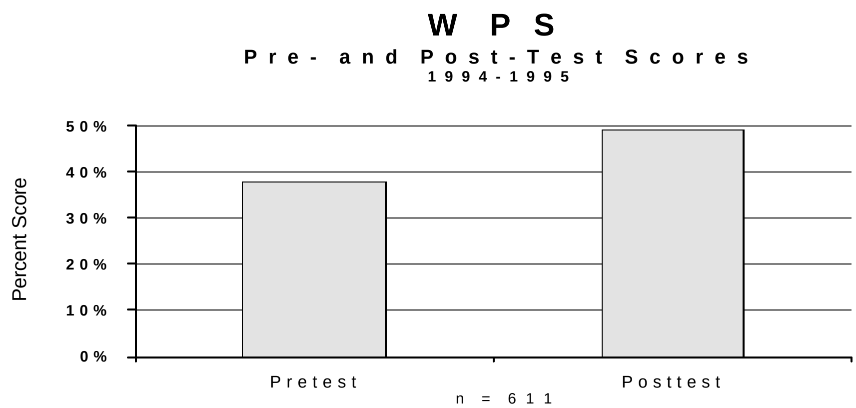


6. Extended Operational Test of the Word Problem Solving Tutor

Dates: Sep 94 - May 95

Description: A large-scale field test of a revised version of WPS (v4.06) was conducted with 611 subjects at eight schools in two states. In order to test the effects on teacher training on WPS implementation, training was shortened to 1 1/2 days from 2 1/2 days.

Outcome: There was no control group during this year. Students improved their word problem-solving performance by 12%. Shortening teacher training did not appear to negatively affect teacher and student use of WPS.

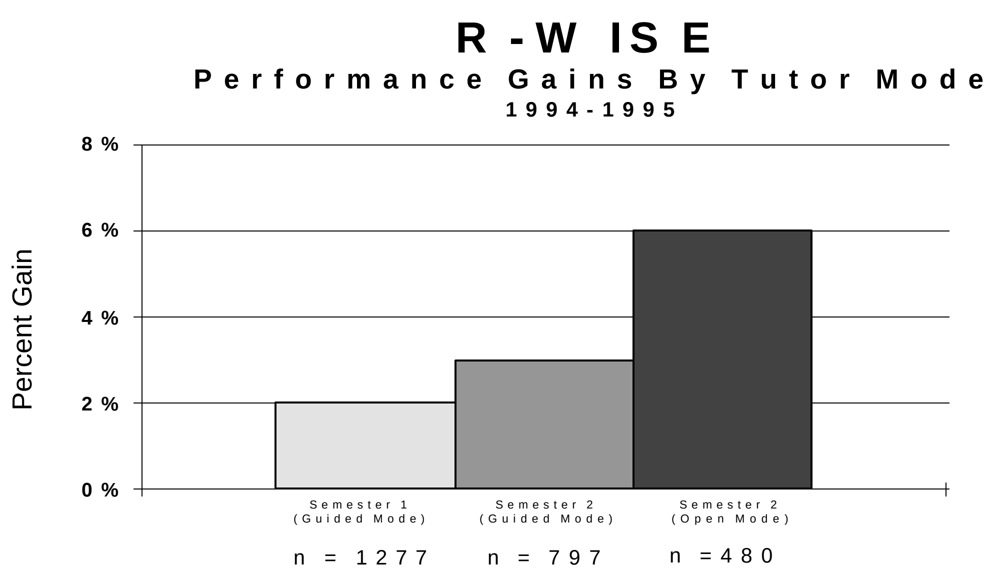


7. A Comparison of Two Instructional Approaches for R-WISE

Dates: Sep 94 - May 95

Description: Data were collected from students using two versions of R-WISE. One version had extended, elaborated instructional modules, which the students were required to complete as they interacted with R-WISE. The other version included shorter, simpler instructional modules. The relationship between teacher style and tutor approach was investigated (Rowley, Miller, & Carlson, 1997).

Outcome: Data from the first semester of the academic year showed positive gains from September through January, though these gains were smaller than previous studies, probably because student contact time with R-WISE was significantly reduced. Due to a network installation "bug" in the updated R-WISE software, teachers used the computer lab less in the second semester. As a result, the data from the spring semester are inconclusive. The data on teacher style interactions indicate that styles of teaching with emphasis on student-centered instruction are more compatible with the tutor produce higher student scores. However, further research is needed before strong conclusions are made concerning the relationship of teacher style and tutoring approach.



8. Instruction in Scientific Inquiry Skills Tutor (ISIS) Pilot Study

Dates: Oct 94 - May 95

Description: A pilot test was conducted to investigate the effectiveness of the first version of ISIS and issues surrounding a long-term operational implementation of ISIS in a high school setting. The treatment group consisted of approximately 400 students in 16 sections of ninth grade biology with four teachers for approximately 15 hours of instruction. Ten other sections of freshman biology at the same high school served as the control sample.

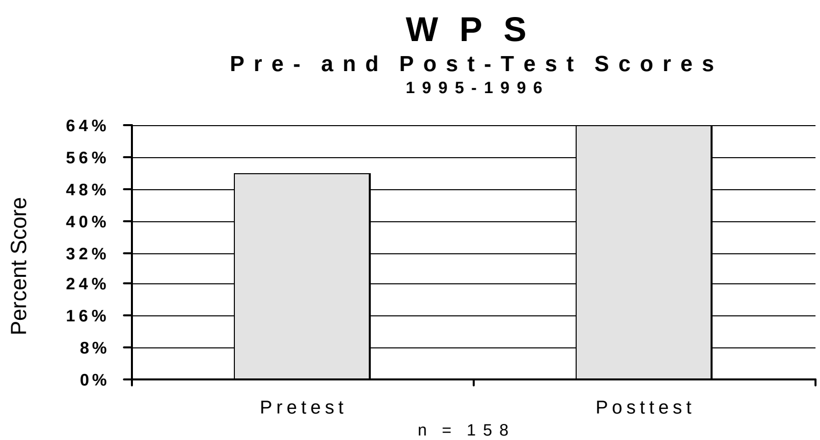
Outcome: Students using ISIS gained more scientific inquiry skills during the academic year than their control counterparts. Qualitative data from teacher-student-computer interactions indicated several directions for refinements for the subsequent version of ISIS.

9. Small School Implementation of WPS

Dates: Jan 96- May 96

Description: WPS 4.06 was implemented in 10 rural sites in New Mexico. Teacher training was shortened to one day in order to test the effects of reduced teacher training sessions on the implementation of WPS. We are also testing the instructional effectiveness of an updated version of WPS in those schools.

Outcome: Students showed gains comparable to previous years. Students improved their word problem-solving performance by 6%. We met with site coordinators from the rural sites to collect information on the implementation of WPS in their schools. Site coordinators from schools with only one math teacher using WPS reported that their teachers sometimes needed to discuss questions with other teachers. We are addressing how to help users in remote sites.

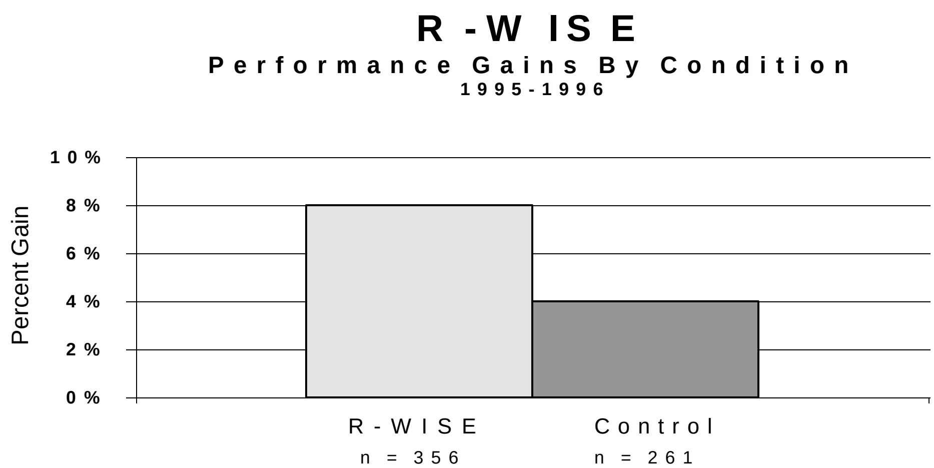


10. Addressing Replicability and Measurement Issues in R-WISE studies

Dates: Sep 95 - May 96

Description: Data were collected from students using the previous year's version of R-WISE in a replication study. Research design also tested for equivalence of two presumably parallel writing prompts. The study included 356 students of 8 English teachers in the treatment group and 261 students of 5 English teachers in the control group, with 39 English classes participating (Rowley, Miller, & Carlson, 1997).

Outcome: Findings supported the results of previous studies. Results indicated a small but significant effect of the R-WISE condition on learning outcomes. Results also raised questions as to the reliability of the two prompts certified as equivalent. Field input regarding lessons learned suggested directions for the design of a follow-on writing process tutor, *Maestro*.

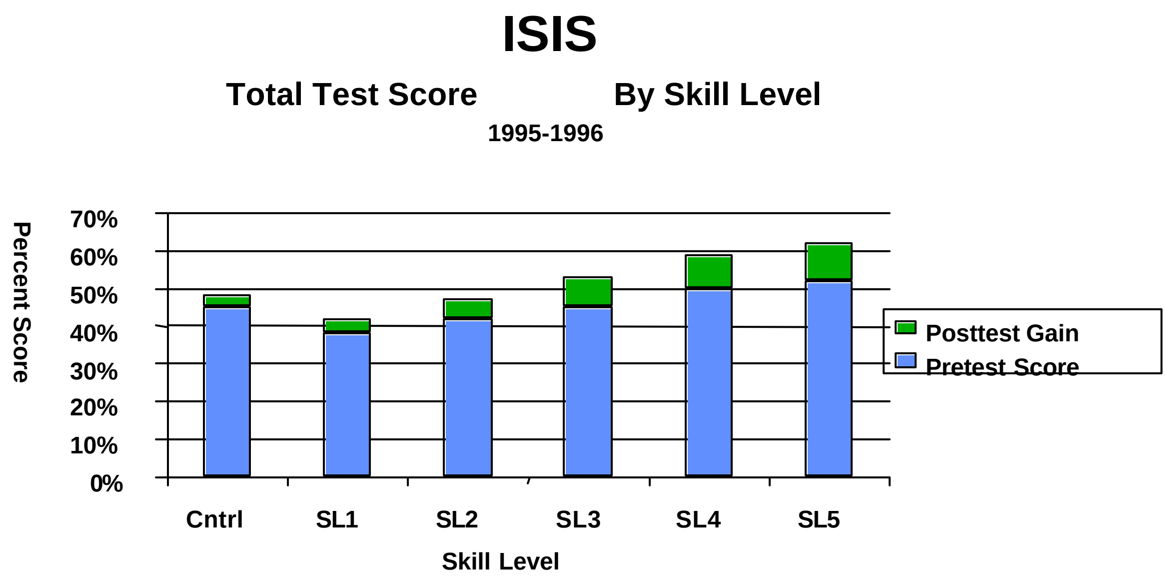


11. Instruction in Scientific Inquiry Skills (ISIS) Tutor Large-scale Implementation Study

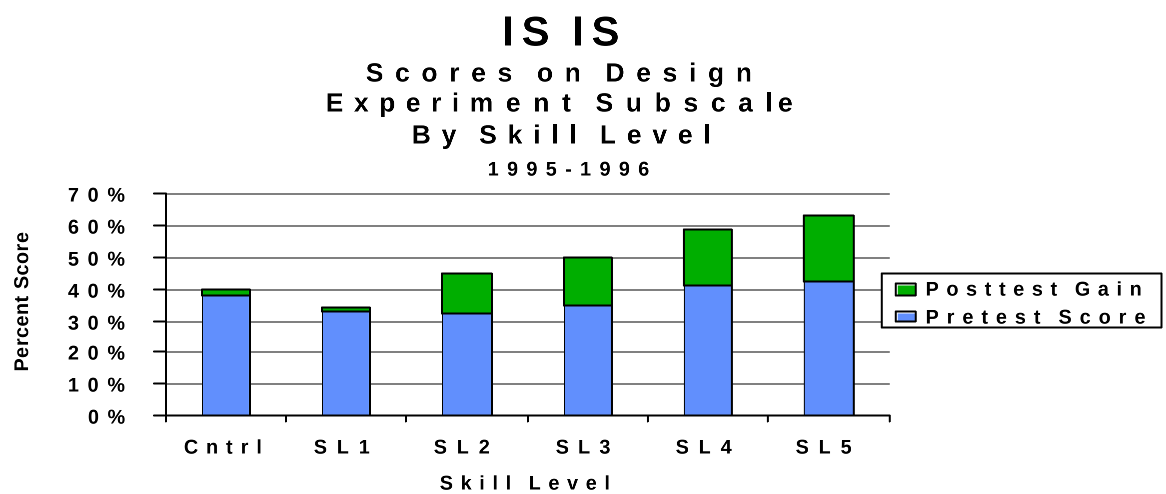
Dates: Sep 95 - May 96

Description: A large-scale test of the effectiveness and implementation of ISIS was conducted in 14 schools in five states. There were over 30 teachers using ISIS in 83 sections of ninth-grade biology. There were 46 sections in the same high schools serving as non-treatment control groups. We also investigated the feasibility of using ISIS in 7th grade honors biology and we explored several research questions concerning the use of concept mapping in a knowledge-rich domain (Steuck & Miller, 1997).

Outcome: Observing the overall gains, the treatment group improved by 8%, while the control group improved by only 4%. Specifically, the skill level obtained by the students directly influenced the amount of gain. Students using ISIS (having met a threshold of assignments completed) outperformed control group students on scientific inquiry skills as measures of domain knowledge. Teacher and student focus groups were used to improve the design and implementation of ISIS.



The scores of the design experiment subscale demonstrate the fact that students who used ISIS and obtained higher skill levels outperformed control group students on scientific inquiry skills as measures of domain knowledge.

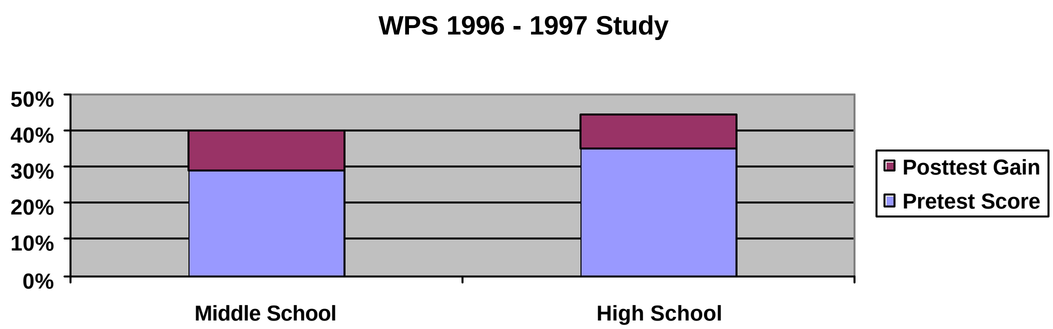


12. A Study of the Effectiveness of the Commercial Version of WPS

Dates: Sep 96 - May 97

Description: The commercial version of WPS was fielded in two middle schools in San Antonio and three high schools in New Mexico to examine the effectiveness of WPS with younger student populations and to replicate previous results.

Outcome: Students showed gains comparable to previous years. Overall, students (n = 244) improved their word problem-solving performance by 9%. Specifically, upward gains for the middle schools (n = 63) were 14% while the high schools (n = 181) showed an 11% upward gain.

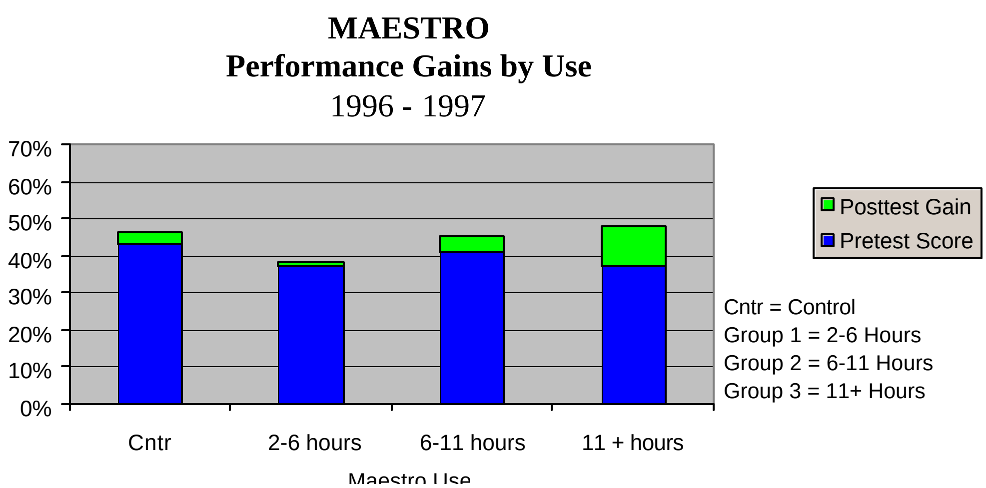


13. Maestro: The Writing Process Tutor Initial Functionality Study

Dates: Sep 96 - May 97

Description: Maestro was designed as a follow-on tutor to R-WISE, based on results of the R-WISE studies, teacher input, cognitive research into the writing process, and the cognitive apprenticeship instructional strategy. The functionality and efficacy of the initial version of Maestro was tested in a large-scale pilot study. The study groups include classes of 54 teachers at 23 schools.

Outcome: Similar to results with the other tutors in the FST suite, student gains were directly influenced by the amount of time spent on the Writing Process Tutor. Specifically, students spending at least 11 hours using Maestro improved by 11% while the control group improved by only 3%.

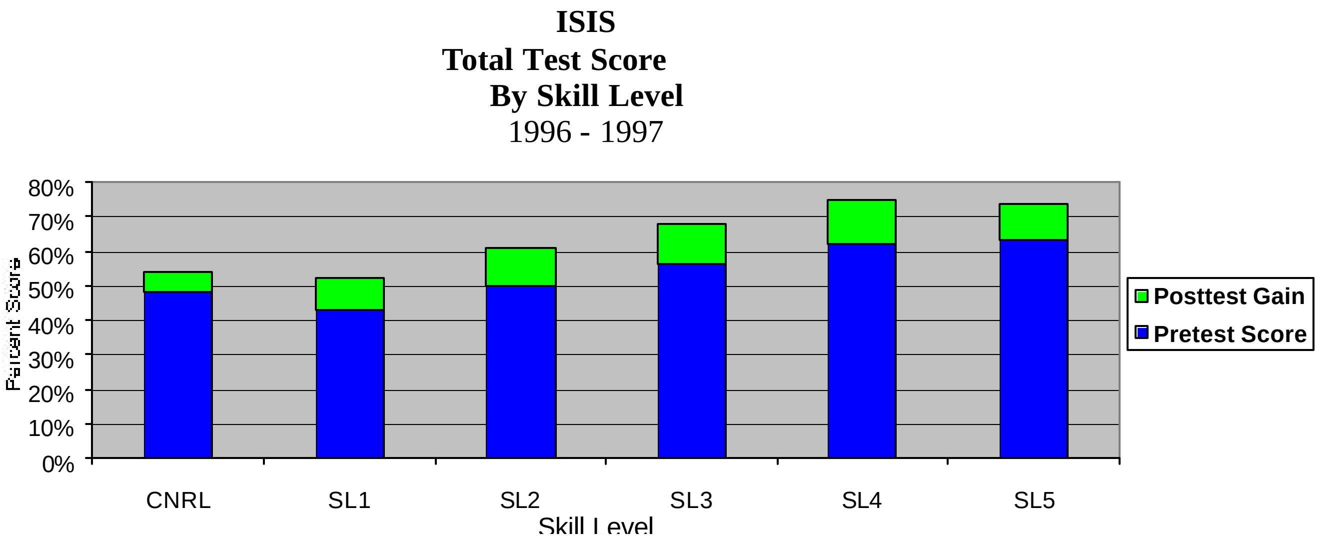


14. ISIS: A Replication Study

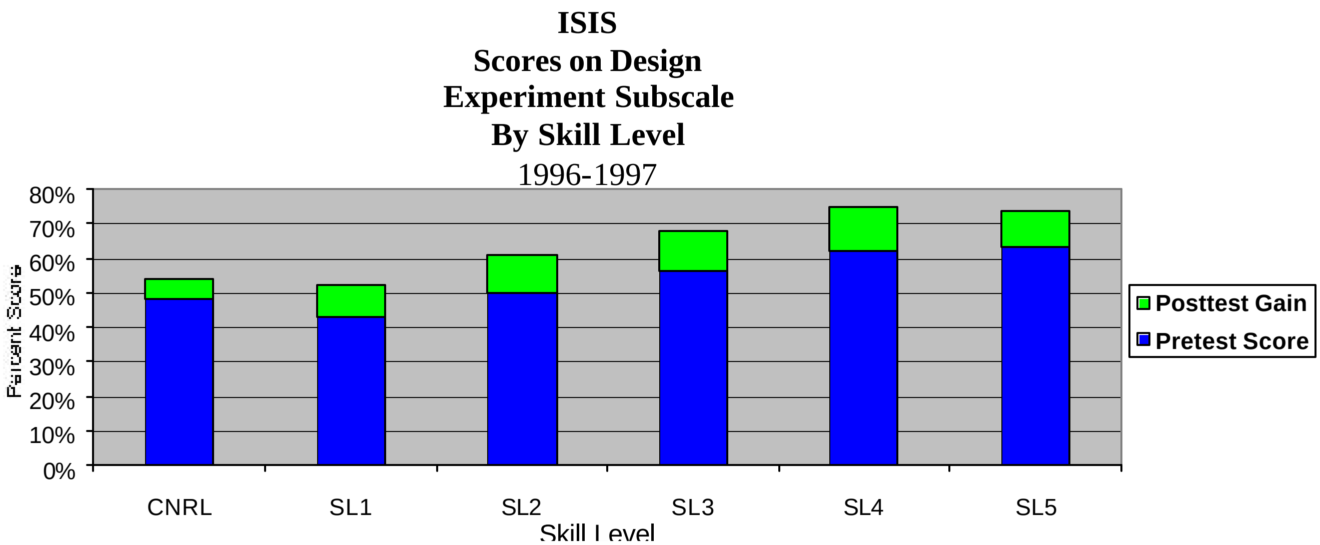
Dates: Sep 96 - May 97

Description: The purpose of this study was to replicate previous findings with the newest version of the software in 19 schools with over 30 teachers utilizing ISIS (Meyer, Steuck, Miller, Pesthy, & Kretschmer, 1999).

Outcome: Observing the overall gains, the treatment group improved by 11%, while the control group improved by only 6%. Specifically, the skill level obtained by the students directly influenced the amount of gain. Once again, students using ISIS (having met a threshold of assignments completed) outperformed control group students on scientific inquiry skills as measures of domain knowledge. Teacher and student focus groups were again used to improve the design and implementation of the next iteration of the tutor.



As seen in the past study, the design subscale showed that students who used ISIS and obtained higher skill levels outperformed control group students on scientific inquiry skills as measures of domain knowledge.



15. A Replication Study of WPS When External Requirements Are Decreased

Dates: Sep 97 - May 98

Description: This study looked at the effectiveness of the software when external requirements were decreased for the school staff. During the school year, the technical support remained readily available and site coordinator meetings were held. However, teachers and site coordinators were not required to complete monthly progress reports or participate in weekly meetings and the project staff eliminated site visits.

Outcome: The data were collected, but not analyzed due to project downsizing.

16. Maestro: A Replication Study

Dates: Sep 97 - May 98

Description: The purpose of this study was to replicate previous findings with the newest version of the software in 19 schools with over 30 teachers utilizing Maestro.

Outcome : The data were collected but not analyzed due to project downsizing.

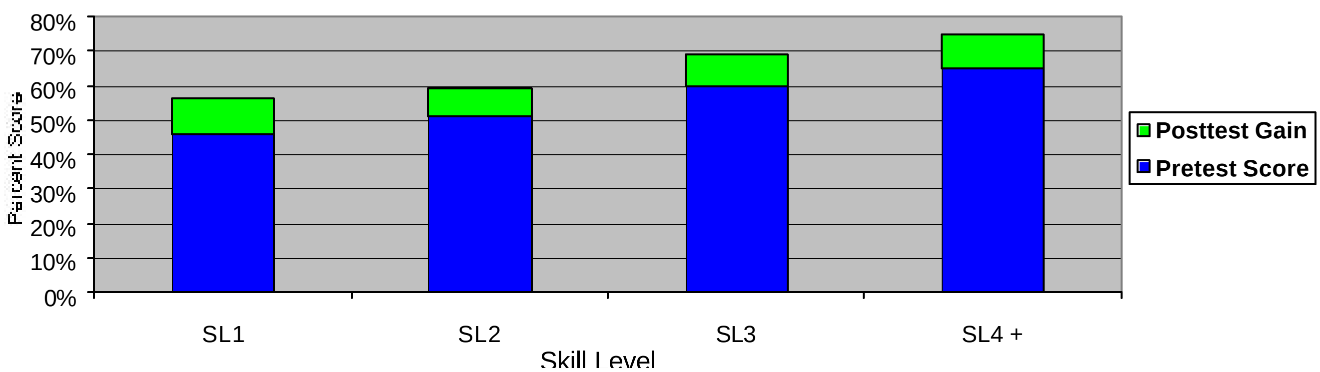
17. ISIS: A Replication Study

Dates: Sep 97 - May 98

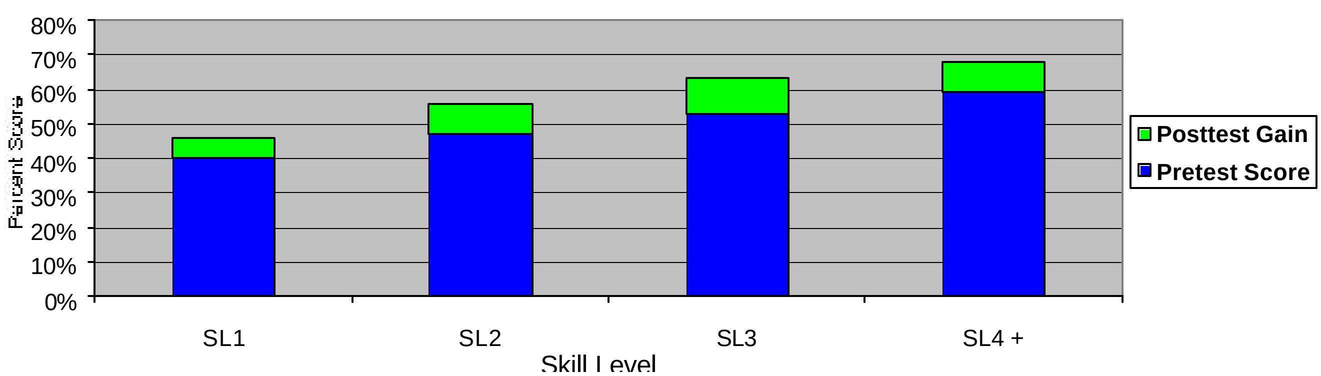
Description: The purpose of this study was to replicate previous findings with the newest version of the software in four schools with nine teachers utilizing ISIS (Meyer, Miller, Steuck, & Kretschmer, 1999).

Outcome : The results again depicted a linear trend with students who completed more assignments showing larger gains on both a Skills and Content Test.

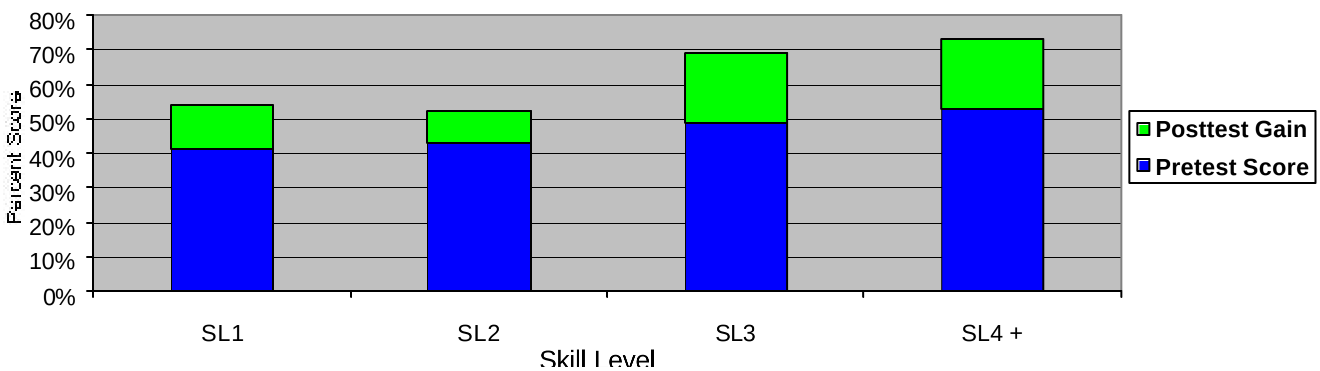
ISIS
Total Test Score on Skills Test By Skill Level
1997 - 1998



ISIS
Total Test Score on Content Test By Skill Level
1997 - 1998



ISIS
Scores on Design Experiment Subscale
(Skills Test) By Skill Level
1997-1998



Consistent with the earlier ISIS studies, the design subscales show that as students obtain higher skill levels their knowledge is increasing. It appears that there exists a threshold for students to develop a coherent understanding of scientific inquiry. Students may have to progress to a certain level of experience with scientific inquiry activities in order to get “the big picture.” This is supported by the design of ISIS in that students reaching the third level of skill development use the simulated biomes to conduct their experiments. It is at this point that they carry out a wide range of scientific activities: planning and conducting their experiments.

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Meyer, T., Steuck, K., Miller, T., Pesthy, C., & Kretschmer, M. (1999, March). Teaching scientific inquiry skills with an intelligent tutoring system. Proceedings of the Mathematics/Science Education & Technology, 492 - 495, San Antonio, TX

Meyer, T. N., Miller, T. M., Steuck, K., & Kretschmer, M. (1999). A multi-year large-scale field study of a learner controlled intelligent tutoring system. Proceedings of the 9th International Conference on Artificial Intelligence in Education, Le Mans, FR.

Steuck, K. & Miller, T. (1997, March). An evaluation of an authentic learning environment for teaching scientific inquiry skills. Paper presented at the Annual meeting of the American Educational Research Association, Chicago, IL.

Wheeler, J. L., & Regian. J. W. (1999). The use of a cognitive tutoring system in the improvement of the abstract reasoning component of word problem solving. Computers in Human Behavior, 15, 243-254.

APPENDIX F: FUNDAMENTAL SKILLS TRAINING PUBLICATION LIST

Papers & Articles

Carlson, P. & Crevoisier, M. (1994). R-WISE: A computerized environment for tutoring critical literacy. Proceedings of the ED-MEDIA 94 World Conference on Educational Multimedia and Hypermedia, Canada.

Carlson, P. A. & Crevoisier, M. L. (1995). R-WISE: A learning environment to teach prose composition. (AL/HR-TP-95-004, AD A303684). Brooks, AFB, Texas: Armstrong Laboratory.

Carlson, P. A.; Hitzfelder, E.; Hudson, T.; & Redmon, D. (1996, March). Classrooms as testbeds for educational software design. T.H.E. Journal, 75-78.

Carlson, P.A. & Larralde, V. (1995). Combining concept mapping and adaptive advice to teach reading comprehension. (AL/HR-TP-95-005, AD A303683). Brooks, AFB, Texas: Armstrong Laboratory.

Carlson, P. A. & Miller, T. M. (1996). Beyond word processing: Using an interactive learning environment to teach writing. (AL/HR-TR-96-0090, AD A319034). Brooks, AFB, Texas: Armstrong Laboratory.

Carlson, P. A. & Miller, T. M. (1996). R-WISE: Empirical evaluation of a cognitive tool for strategy acquisition in prose composition. Proceedings of the ED-MEDIA 96 World Conference on Educational Multimedia and Hypermedia, Boston.

Larralde, V. & Carlson, P. A. (1994). R-WISE: Reading and writing in a supportive environment. Proceedings of the ED-MEDIA 94 World Conference on Educational Multimedia and Hypermedia, Canada.

Meyer, T. N., Miller, T. M., Steuck, K., & Kretschmer, M. (1999, July). A multi-year large-scale field study of a learner controlled intelligent tutoring system. Proceedings of the 9th International Conference on Artificial Intelligence in Education, Le Mans, FR.

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Rowley, K. (submitted). Re-engineering existing learning technologies: Designing Maestro, a second generation writing tutor. Technical Report of U.S. Air Force Research Laboratory, HEJT, Brooks AFB, Texas.

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